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Transportation Research Procedia 14 (2016) 133 – 142
Transportation Research Procedia
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6th Transport Research Arena April 18-21, 2016

Green maritime logistics: the quest for win-win solutions

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Abstract

By green maritime logistics we mean achieving an acceptable environmental performance of the maritime transport logistical supply chain while at the same time respecting traditional economic criteria. In this paper the environmental focus is on maritime emissions. Achieving such goal may involve several trade-offs, and win-win solutions are typically sought. However, finding these solutions may be more difficult than may appear at first glance. The purpose of this paper is to provide a concise overview of the challenges of green maritime logistics and present some examples, both for greenhouse gas (GHG) and non-GHG emissions.

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Green maritime logistics; green transport logistics; sustainable maritime logistics; green shipping

1. Introduction

The traditional analysis of maritime transport logistics problems has been in terms of cost- benefit, economic or other optimisation criteria from the point of view of the logistics provider, carrier, shipper, or other end-user. Such traditional analysis by and large either ignores environmental issues, or considers them of secondary importance. Green maritime logistics tries to bring the environmental dimension into the problem, by analyzing various trade-offs and exploring 'win-win' solutions. In doing so, criteria for the benefit of the private end user may give their place to criteria that are more relevant from a societal point of view.

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.049

There can be many definitions of the word 'green', and a definition can be critical as regards the subsequent approach and measures to achieve whatever goal is set. For instance, if by green we mean minimising emissions from maritime transport, and we subsequently strive to apply a series of technological measures that would achieve that goal, a conceivable outcome might be that shipping may become unprofitable and various undesirable side-effects may occur, including cargo shifts to other modes, reduction of trade, route shutdown, relocation or even shutdown of production, and possibly others. It is clear that one can always minimise emissions from A to B if trade from A to B is minimised. In the extreme case that trade from A to B ceases to exist because no operator would make a profit engaging in that trade, emissions would drive down to zero. But that's not a desirable outcome.

So things may be more complex than they appear at first glance, and in fact the goal of greening the maritime logistical supply chain may involve several trade-offs that are at stake, and which have to be analyzed and evaluated if a desirable solution is to be achieved. In the long road towards a sustainable global maritime transport system, a sound knowledge of the balances between economic and environmental objectives, and of the factors that may affect these balances, is a necessary condition.

Based on the above, below is a working definition of the phrase 'green maritime logistics':

- *Green maritime logistics is an attempt to attain an acceptable environmental performance in the maritime transport supply chain, while at the same time respecting traditional economic performance criteria.*

Societal criteria are often embedded in the above definition, either on their own right, or as part of the set of economic criteria. It is clear that the weights among the various criteria varies among stakeholders, a private operator assigning more weight to economic criteria, an environmental organisation more weight to environmental criteria, and others perhaps preferring social criteria. Whatever it is, achieving the above is what we call a 'win-win' scenario. As we will see however, a win-win outcome may not always be achievable. The word 'sustainable' is often used to denote a similar outcome, and *sustainable maritime logistics* is often meant to imply a maritime transport system that combines acceptable economic, environmental and social performances.

We clarify that in the above definition by 'acceptable environmental performance' and for the purpose of this paper we mainly mean *acceptable level of emissions*. This is so due to the increased attention anthropogenic emissions have been getting in recent years, both at a global and a regional level. Among them, certainly carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions have attracted much of the focus from a climate change perspective and the world community has set ambitious goals to mitigate them. Other types of emissions, such as sulphur oxides (SOx), nitrogen oxides (NOx) and others are also important. We make the above clarification because it should be recognised that, other than emissions, there are certainly additional environmental attributes of maritime transport that may create undesirable effects. These include noise, hazardous substances, oil pollution, ballast water, dust, residues, garbage, and others.

The above definition also implies that there exists a well-defined set of criteria to assess the various facets of performance of the logistical system under consideration. These criteria are often called Key Performance Indicators (KPIs). Selecting appropriate and meaningful KPIs is a very important step and one that may be more difficult than it seems at first glance. Difficulties may be due to a variety of reasons, as will be seen later.

With these in mind, the purpose of this paper is to present a brief discourse of the main issues associated with green maritime logistics, and present some examples that are relevant in this area. Due to space limitations, we should clarify that the paper covers only a limited sample of relevant topics, referring to additional publications for more details. The broader perspective of green *transport* logistics, in which shipping is one of the global transport modes, is examined in a recent book by the author (Psaraftis, 2015).

The rest of this paper is organised as follows. Section 2 discusses the main challenges associated with green maritime logistics and Section 3 discusses the difficulties in obtaining win-win solutions. Section 4 refers to logistics-based measures for shipping, with a focus on speed optimisation and the problem of SOx reduction, and Section 5 presents the conclusions of the paper.

2. Challenges in green maritime logistics

Green maritime logistics presents some non-trivial challenges. Below we present a non-exhaustive sample.

2.1. Ambitious environmental goals

The EU 2011 White Paper on Transport (EU, 2011) aims, at a high-level target, at reducing by year 2050 transport-related GHG emissions by *at least 60%* with respect to 1990 levels. Lower-level targets that are related to the sustainability of transport include the following:

- By 2030, halve the use of ‘conventionally-fuelled’ cars in urban transport; by 2050, phase them out in cities;
- By 2030, achieve essentially CO_2-free city logistics in major urban centers.
- By 2030, 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport, and more than 50% by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure to be developed.
- By 2050, reduce EU CO_2 emissions from maritime bunker fuels by 40% (if feasible by 50%).
- By 2050, increase the use of low-carbon sustainable fuels in aviation to 40%.
- Move towards full application of ‘user pays’ and ‘polluter pays’ principles and private sector engagement to eliminate distortions, including harmful subsidies, generate revenues and ensure financing for future transport investments.

Challenges in other parts of the developed world (including North America, Japan, and Australia) are quite similar. They may be even more pronounced in developing economies in Asia, South America and Africa. Many of the latter countries question the basic premise that they should be subject to the same kinds of environmental guidelines as in developed economies, on the ground that this may impede their own economic development. International bodies such as the United Nations Framework Conference on Climate Change (UNFCCC) and others are routinely presented with arguments centring on what is known as the Common But Differentiated Responsibilies (CBDR) principle, which gives developing countries ground for such a position.

As regards maritime transport, the global scene is equally challenging. As early as in 1997 in Kyoto, the UNFCCC designated the International Maritime Organization (IMO), the United Nations specialised agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships, as the body responsible for regulating maritime air emissions. However, progress on that front has generally been slow. In 2008, the Marine Environment Protection Committee (MEPC) of the IMO adopted amendments to the MARPOL Annex VI regulations that deal with SO_x and NO_x emissions. But on the GHG front, and in spite of much discussion, shipping is still not being included in the UNFCCC global emissions reduction target for CO_2 and other GHGs, and in fact until very recently, shipping was the only mode of transport for which GHG emissions were not regulated. The era of non-regulation for shipping GHGs officially came to an end in July 2011, when the MEPC adopted the Energy Efficiency Design Index (EEDI) for new ships. EEDI is a benchmarking scheme aiming to provide an indication of a merchant ship’s CO_2 output in relation to its transport work. Adoption of EEDI was the first step of IMO’s drive to reduce CO_2 emissions from shipping. The EEDI compares design-level CO_2 emissions and transport work of a vessel and benchmarks this ratio against an IMO-set requirement.

The EEDI of a new ship is to be compared with the so-called ‘EEDI (reference line),’ which is defined as:

$$\text{EEDI (reference line)} = a\text{DWT}^{-c} \tag{1}$$

where DWT is the deadweight of the ship and a and c are positive coefficients determined by regression from the world fleet database, per major ship category. For a given new ship, the attained EEDI value should be equal or less than the required EEDI value which is provided by the following formula:

$$\textit{Attained EEDI} \leqq \textit{Required EEDI} = (1\text{-}X/100)\, aDWT^{-c} \tag{2}$$

where X is a 'reduction factor' specified for the required EEDI compared to the EEDI (reference line) [1].

In addition to GHGs, IMO regulates the emission of air pollutants from ship exhausts, including NOx and SOx emissions. These regulations are contained in the MARPOL Annex VI protocol which, in addition, designates specific geographic areas in Europe and North America as Emission Control Areas (ECAs), where more stringent requirements apply. An ECA can be designated for NOx and PM, or SOx, or all three types of emissions from ships (the term SECA is used for a SOx ECA). The latest revision of MARPOL Annex VI was adopted in October 2008. Its basic provisions that relate to SOx emissions include:

- a reduction in the global limit of sulphur content in fuel to 3.5% by mass (from 4.5%) effective from 1 January 2012; then to 0.5%, effective from 1 January 2020 subject to a feasibility review to be completed no later than 2018 (it can be postponed to 1 January 2025 if the review reveals that not enough fuel with a sulphur content of 0.5% is available for global shipping in 2020),
- a reduction in sulphur limits for fuels in SECAs to 1%, beginning on 1 July 2010 (from 1.5%); being further reduced to 0.1%, effective from 1 January 2015,
- the possibility of using suitable abatement equipment as an alternative to fuel switching requirements on the basis that equivalent SOx emissions are achieved on a continuous basis.

At a European level, these provisions were not transposed into European law until November 2012, when Directive 2012/33/EU was adopted. The Directive aligns to the IMO regulations and brings the 0.5% limit into force on 1 January 2020 for all EU sea territory, even if on global scale this limit gets postponed to 2025. Furthermore, the Commission's proposal for passenger ships to follow the SECA limits of 0.1% also outside the SECA area from 2020 onwards was not approved, and the current 1.5% limit will be lowered to 0.5% in 2020 as for all shipping within the EU. The 0.1% limit, effective as of 1 January 2015 within SECAs, can only be achieved by fitting expensive exhaust scrubbers, consuming LNG, or burning Marine Gas Oil, which is currently around \$300 per tonne more expensive that Heavy Fuel Oil 1.0%S. This is expected to have adverse effects on shipping and ports in SECAs, as well as the industries that depend on their services.

2.2. Measurability

A second challenge, and one that is not mentioned frequently, concerns measurability. In the quest to reduce maritime transport emissions, one may pose the naïve question, can we at least measure them with some degree of confidence? It is clear that to reduce anything, one should be able to measure it first. However, it turns out that emissions from various sources are not being measured directly and the only data that exist are *estimates* of these emissions. Even for past emissions, these estimates are produced by specific methods, most of which involve modeling and various assumptions on model inputs such as fuel consumptions and speeds of vehicles, activity profile of fleet, fuel sales, and others. These estimates can vary significantly, depending on the method. The third GHG study (IMO, 2014) provided updated estimates of CO_2 emissions from international shipping from 2007 (baseline year of the second GHG study) to 2012. The 2012 figure, estimated by a 'bottom up' method, was 796 million tonnes, down from 885 million (updated figure) in 2007, or 2.2% of global CO_2 emissions. CO_2 from all shipping was estimated at 940 million tonnes, down from 1,100 tonnes in 2007. The reduction was mainly attributed to slow steaming due to depressed market conditions after 2008.

The IMO work on Market Based Measures (MBMs) for GHGs involved some 10 distinct proposals submitted by various delegations in 2010. After long discussions, this work was suspended in May 2013 in the wake of a clash between developed and developing Member States at MEPC 65. One month later, the European Commission issued its proposal for a Regulation on monitoring, reporting and verification of CO_2 emissions, the so-called MRV proposal, as a first step towards setting GHG reduction targets and taking further measures, including an MBM.

[1] The values of X specified by the IMO are 0% for ships built from 2013-2015, 10% for ships built from 2016-2020, 20% for ships built from 2020-2025 and 30% for ships built from 2025-2030. This means that it will be more stringent to be EEDI compliant in the years ahead.

The immediate objective of the MRV proposal is to produce accurate information on the CO_2 emissions of large ships using EU ports and incentivise energy efficiency improvements by making this information publicly available. In this way, the Commission sets the ground for possible future MBMs or efficiency standards, while at the same time attempts to address one of the market barriers found to prevent the implementation of cost-effective abatement measures by the industry, namely the lack of reliable information on fuel efficiency of ships. Yet, another stated objective of introducing an MRV system is the securing of more time to discuss emission reduction targets and relevant measures, particularly at global level in IMO.

The proposed MRV system applies to ships above 5,000 GRT, regardless of flag, and covers intra-EU, incoming (from the last non-EU port to the first EU port of call) and outgoing (from an EU port to the next non-EU port of call) voyages. It concerns the CO_2 emissions only.

Following the preparation of an emission monitoring plan by the ship-owning company and its approval by an accredited verifier, information on fuel consumption, distance travelled, time at sea and cargo carried is collected by the company for each ship and each journey falling under the Regulation. Actual fuel consumption for each voyage can be calculated using one of the following methods, provided that the method selected is pre-defined in the monitoring plan and, once chosen, is applied consistently:

- Bunker Fuel Delivery Notes and periodic stocktakes of fuel tanks,
- Bunker fuel tank monitoring on board,
- Flow meters and applicable combustion processes, and
- Direct emissions measurements.

Based on these parameters, a number of energy efficiency/emissions indicators are calculated and reported on an annual basis. The annual reports are submitted to the Commission and the flag state after their approval by the verifiers, who issue conformity documents that need to be kept on board the ships covered by the system. Conformity is to be checked by the flag state and through the port state control system. Sanctions are foreseen for the failure to comply, including in certain cases the expulsion of a ship, i.e. banning its entry to EU ports until the compliance problem has been resolved. The energy efficiency performance of the ships falling within the scope of the Regulation is made publicly available by the Commission every year.

As is usually the case, the proposal has attracted criticism from both directions. The environmental groups consider the proposal exceptionally mild, while the shipping interests argue that it imposes unnecessary and maybe impossible to fulfil obligations to an industry that suffers already from excessive administrative burdens.

2.3. Number of stakeholders

A third challenge stems from the number of stakeholders in in this area. These may typically include (list is not exhaustive): shipping companies, shipyards, terminal and warehouse operators, other infrastructure operators, equipment manufacturers, cargo owners (shippers), nongovernmental organisations (NGOs), environmental organisations, classification societies, public officials and politicians, other industries (eg, repair yards, recycling), and R&D organisations and universities. Each of the above stakeholders may have their own agenda and objectives that are many times conflicting with the objectives of other stakeholders. It thus may be difficult to reach consensus solutions and political considerations may sometimes prevail. Adopting the EEDI index for maritime CO_2 emissions in 2011 revealed widely different views between industrialised and developing countries and the solution obtained was *not* a consensus solution.

3. Win-win and the 'push down, pop up' principle

'Win-win' is a nice set of words. But a frequent problem is that finding win-win solutions may not always be easy. More often than not, the 'push-down, pop-up' principle applies: if you push a certain button down, at least another one will pop up somewhere else. Speed reduction in maritime transport is a prime example: if ones make the world fleet go slower, one will reduce emissions, will reduce fuel costs, and will take care of vessel overcapacity, which is important when the market is depressed, as it is these days. That seems like killing three birds in one stone, so it looks pretty good, or in fact a win-win-win proposition. But is that really the case?

The answer is, it depends. Reducing ship speed may have other ramifications, which may not be beneficial. For instance, cargo in-transit inventory costs will generally increase. This is due to the delay in the arrival of the cargo. The inventory costs are proportional to the value of the cargo, so if you really have high-value goods, hauling them at a lower speed may entail significant costs. Another push-down, pop-up effect is that in the short run, freight rates will go up once the overall transport supply is reduced because of slower speeds. At a minimum, the rates will not go down as much, and this may help the market, but shippers will foot the bill. This fact is seldom mentioned in any of the discussions on green maritime policies. The extent of the rate increase would depend on the particular scenario.

Yet another push-down, pop-up effect concerns effects that reduction in ship speeds may have on other modes of transport, to the extent these are alternatives to sea transport. This is the situation as regards many intra-European destinations, but may also be true in North America, if coastal shipping is contemplated to relieve highways from congestion. If ships are made to go slower, shippers may be induced to prefer land-based alternatives, mostly road, and that may increase overall GHG production. Road is certainly worse than maritime in terms of GHG emissions per tonne-km.

Last but not least, a reduction of ship speed, if implemented at the strategic (design) level via a reduction of the ship's installed power, may have ramifications as regards safety, for it may conflict with the minimum safe power that is necessary for a ship to have in adverse weather conditions. Already this problem is a source of intense discussion at the IMO in the context of EEDI, as EEDI compliance and minimum safe power may not necessarily be compatible with one another. Indeed, this can be seen from inequality (1) of Section 2.1, which effectively imposes an upper bound on design speed and hence installed power. This is a highly technical discussion and the jury is still out on how the issue will be resolved. Some industry circles are concerned that it will be very difficult for a ship to be EEDI compliant and have adequate minimum safe power at the same time, and this problem will be more acute in the years to come.

In the search for environmentally friendly policies, it is clear that a holistic approach is necessary, one that looks into and optimises the overall supply chain instead of its individual components. Otherwise, the solutions are likely to be sub-optimal, both cost-wise and environment-wise.

In other transport modes, an example that comes to mind concerns the push for the wide-spread use of electric power for surface transport vehicles, whether these are passenger cars, buses, railway locomotives, or even trucks and bicycles. The EU goal to achieve essentially CO_2 -free city logistics in major urban centres by 2030 depends critically on the successful use of electric technologies in urban vehicles. Yet, a basic premise that does not usually appear in public discussion is that the extra energy necessary to power these electric vehicles should produce less emissions than the emissions of the conventionally-fueled vehicles that are replaced. This is true if this extra energy is produced by nuclear, hydro or solar power, but not necessarily true if it is produced by a coal plant or a plant using fossil fuels.

In shipping, the same is true for 'cold ironing,' that is, the provision of electricity to a ship by plugging into a port's electricity supply system so as to switch off the ship's auxiliary engines at port. This is an idea that originated in the ports of Los Angeles and Long Beach (California, USA) and is likely to be the norm for many world ports in the future. The rationale is minimising in-port emissions. But again, the question is what emissions will be produced by the generation of the extra shore electricity, and if those are less than the emissions saved by switching off the ship's auxiliary power at port. If that extra electricity is (for instance) generated by a coal plant, cold ironing may not such be a good idea.

4. Logistics-based measures for green maritime transport

In this section we try to present some basics, referring the reader to additional publications for more details. It has been customary to break down the spectrum of measures to reduce maritime emissions (GHG and others) into basically three major classes.

- First, *technological* measures include more efficient (energy-saving) engines, more efficient ship hulls and designs, more efficient propellers, cleaner fuels (low carbon content, LNG), alternative fuels (fuel cells, biofuels, etc.), devices to trap exhaust emissions (scrubbers, etc), energy recuperation devices (exhaust heat recovery systems, etc), “cold ironing” in ports, various kites, and others. Compliance with EEDI, which is a *design index*, will mainly induce technological measures.

- Second, *logistics-based* (tactical and operational) measures include speed optimisation, optimised weather routing, optimal fleet management and deployment, network design, efficient supply chain management, and others that may impact the logistical operation.
- Third, we have what we call *market-based measures* or MBMs. These include Emissions Trading Schemes (ETS), a possible tax imposed on fuel, and a variety of others.

It should be clarified that in a sense, the above breakdown is artificial. Indeed, an MBM can induce logistics-based measures in the short run and technological measures in the long run. If for instance fuel price is increased by a tax on fuel, a ship owner may slow steam in the short run and he may build or purchase a more energy efficient ship in the long run. It is also important to note that, in much of the maritime logistics literature, environmental criteria such as emissions reduction are scarce, traditional economic criteria such as cost reduction being the norm. Such criteria can be found in papers dealing with ship routing and scheduling, fleet deployment, fleet size and mix, network design, queuing at ports, transhipment, weather routing and terminal management. Sometimes such economic criteria map directly into environmental criteria: if for instance *fuel cost* is the criterion, as it is directly proportional to *emissions*, if fuel cost is to be minimised as an objective, so will emissions, and the solution is win-win. However, for other objectives this direct relationship may cease to exist and one would need to look at environmental criteria in their own right. Even though such criteria were not very common in the past, the body of knowledge that includes such criteria is growing in recent years. Among the set of maritime logistics problems which are important as regards both economic and environmental criteria, perhaps *speed optimisation* is the most important.

The importance of ship speed on ship emissions can be seen, among others, in Psaraftis and Kontovas (2009), who, inter alia, estimate CO_2 emissions from the world commercial fleet broken down by ship type-size combination. According to their analysis, which was based on 2007 data taken from the IHS Fairplay ship database (45,620 commercial ships accounted for), containerships are the top CO_2 emitters in the world fleet. This was perhaps something to be expected at that time, given the relatively high design speeds of these vessels (20-26 knots) as opposed to those carrying bulk cargoes (13-15 knots) and given the nonlinear relationship between speed and fuel consumption and hence emissions. What was perhaps not so obvious to expect was that just the top tier category of container vessels (712 vessels of 4,400 TEU and above) produced 110.36 million tonnes of CO_2 emissions, which was higher than the 106 million tonnes produced by the entire crude oil tanker fleet (2,028 vessels). This means that if ship speed were to be reduced, perhaps uniformly across the board, or even selectively for some categories of vessels, emissions would be reduced too, perhaps drastically.

Reducing ship speed could also have important side benefits: cost reduction is one, and helping a depressed market in which shipping overcapacity is the norm these days is another. In that sense, reducing ship speed may conceivably be a ‘win-win’ proposition. Even though ships travel slower than the other transport modes, a basic premise has always been that there is value in ship speed. As long-distance trips may typically last one to two months, the benefits of a higher speed may be significant: they mainly entail the economic added value of faster delivery of goods, lower inventory costs and increased trade throughput per unit time.

Perhaps the most significant factor that is making a difference in recent years is fact that a ship has to be environmentally friendly as regards air emissions. Because of the non-linear relationship between speed and fuel consumption, it is obvious that a ship that goes slower will emit much less than the same ship going faster. If one starts with the simple way to reduce fuel costs (and by extension emissions) by reducing speed, this can be done at two levels. One level is the technological one, that is, build future ships with reduced installed horsepower so that they cannot sail faster than a prescribed speed. The first cellular containerships of the late 60s and early 70s that went up to 33 knots in the late 1960s when fuel was cheap are gone forever. Maersk’s new flagship ‘Triple-E’ fleet of 18,000-TEU containerships have a design speed of 17.8 knots, down from the 20 - 26 knots range that has been the industry’s norm, and will emit 20% less CO_2 per container moved as compared to the *Emma Maersk*, previously the world’s largest container vessel, and 50% less than the industry average on the Asia-Europe trade lane (Maersk, 2013).

The other level of speed reduction is the logistics-based (tactical/operational) one. At that level, an existing ship can sail slower than its design speed. In shipping parlance this is known as “slow steaming” and may involve just slowing down or even ‘derating’ a ship’s engine, that is, reconfiguring the engine so that a lower power output is achieved, so that even slower speeds can be attained. Such a reconfiguration may involve dropping a cylinder from the main engine or other measures. Depending on engine technology, 'slow steaming kits' are provided by engine manufacturers so that ships can smoothly reduce speed at any desired level. In case speed is drastically reduced, the practice is known as "super slow steaming".

At the same time, and even though win-win solutions may look as natural consequences of speed reduction, the practice may have other ramifications which may not be beneficial. For instance, in the long run more ships will be needed to produce the same transport throughput, and this will entail some costs, some of them financial and some environmental, such as lifecycle emissions due to shipbuilding and recycling. For a comprehensive analysis of lifecycle emissions in maritime transport see Chatzinikolaou and Ventikos (2015).

Yet another side effect of speed reduction is that in the short run, freight rates will go up once the overall transport supply shrinks because of slower speeds. Reducing speed may help a depressed market, but it is the shippers who will suffer and in fact they will do so in two ways: they will pay more, and receive their cargo later. For a discussion how tanker spot rates may be impacted as a result of slow steaming see Devanney (2007).

Last but not least, another possible side effect concerns effects that speed reduction may have on other modes of transport; to the extent these are alternatives to sea transport. This is the situation mostly as regards short-sea trades, in Europe but also in North America. If ships are made to go slower, shippers may be induced to prefer land-based transport alternatives, mostly road, and that may increase overall GHG emissions. Even in long-haul scenarios such as the Far East to Europe trade, some cargoes may tempted to use the rail alternative (for instance via the Trans-Siberian railway) if the speed of vessels is low enough. Psaraftis and Kontovas (2010) develop modal-split models that can be used to investigate such problems.

Dealing with speed is not new in the maritime transport literature and this body of knowledge is rapidly growing. In Psaraftis and Kontovas (2013) some 42 relevant papers were reviewed and a taxonomy of these papers according to various criteria was developed. Several additional papers dealing with ship speed appeared after the above paper was published. Its Google Scholar citations in December 2015 stood at 81, of which there was even a related paper in *Meat Science* (Mills et al., 2014). This indicates a growing interest of researchers in this topic. An amended taxonomy that included 51 papers was presented in Psaraftis and Kontovas (2015a).

A basic property of optimal ship speeds is not immediately obvious. It applies mainly to the charter (tramp) market and compares, for a specific ship and a specific route, the speed optimisation problem of its ship owner and that of a time charterer who may charter the same ship. The ship owner wants to maximise average profit per day and the charterer wants to minimise average cost per day. Even though these two optimisation problems appear at first glance different, the optimal ship speed for both problems turns out to be the same. In Psaraftis and Kontovas (2013) it was shown that both the above problems reduce to the following optimisation problem:

$$min_v \left(\rho f(v) - Q \frac{v}{L} \right) \tag{3}$$

where v is the sailing speed (in nautical miles per day), $\rho=P_{FUEL}/s$, P_{FUEL} =fuel price (in \$/tonne), s is the spot rate received by the owner (in \$/tonne), $f(v)$ is the ship's daily fuel consumption (in tonnes/day), Q is the ship's cargo capacity (tonnes), and L is the roundtrip distance (in nautical miles).

It can be seen that a key determinant parameter of the speed optimisation problem is ρ, *the non-dimensional ratio of the fuel price divided by the market spot rate*. Higher ρ ratios will generally induce lower speeds than lower ratios. This reflects the typical behaviour of shipping lines, which tend to slow steam in periods of depressed market conditions and/or high fuel prices and go faster if the opposite is the case.

Speed optimisation can be extended into combined ship routing and speed scenarios. A number of papers in the literature have looked at such combined scenarios, see for instance Hvattum et al. (2013), Fagerholt and Ronen (2013), and Psaraftis and Kontovas (2014), among others. In the latter reference the authors show, among other things, that a ship sailing the minimum distance route at the minimum permissible speed may not minimise emissions. The reason is that the minimum distance route may involve more legs in which the ship is more laden as compared to the case it sails an alternate, longer route. A heavier load profile results in higher fuel consumption (and emissions) overall, even though the route may be shorter. So in this case what would intuitively seem like an optimal policy is actually suboptimal.

Psaraftis and Kontovas (2015b), among other things, provide a discussion on the possible impact of slow steaming on port operations. If a port is congested, it would clearly make no sense to sail there at full speed, wasting money on fuel and producing emissions that can be avoided if ship speed were slower. A recent initiative is the so-called 'Virtual Arrival', which has been used in order to manage the vessels' arrival time based on the experience of congestion at some discharging ports. This initiative recognises known inefficiencies in the supply chain, such as waiting to discharge because of port delays and reduces fuel consumption and, consequently, emissions by implementing a mutually-agreed reduction in a vessel's speed in order to achieve an agreed arrival time at a port. After the agreement of both parties the ship slows to the economic speed based on the revised arrival time. Once the voyage is completed, demurrage is calculated based on the original plans and bunker savings are spilt between the parties. In another direction, Magirou et al. (2015) developed models that optimise speed in a dynamic and stochastic setting. It was found that for market freight rates that depend on a Markovian random variable, economic speed depends on the market state as well, with increased speed corresponding to good states of the market.

As regards SO_x emissions, even though the amounts of SO_x produced by ships are substantially lower than CO_2, SO_x emissions are highly undesirable as they cause acid rain and undesirable health effects in humans and animals. To mitigate these adverse environmental effects, the international shipping community has taken substantial policy measures. With the introduction of new limits for the content of sulphur in marine fuels in Northern European and North American ECAs, short-sea companies operating in these areas will face substantial additional cost. As stated earlier, as of 1/1/2015 international regulations stipulate, among other things, a 0.1% limit in the sulphur content of marine fuels, or equivalent measures limiting the percent of SO_x emissions to the same amount. Even after the precipitous drop of fuel prices after mid- 2014, low-sulphur fuel is substantially more expensive than HFO. Unlike its deep-sea counterpart, in short-sea shipping such a freight rate increase may induce shippers to use land-based alternatives (mainly road). A reverse shift of cargo would go against the EU policy to shift traffic from land to sea to reduce congestion, and might ultimately (under certain circumstances) increase the overall level of CO_2 emissions along the entire supply chain. The reader may refer to, among others, Cullinane and Bergvist (2014), Panagakos et al. (2014), and Kontovas et al. (2015) for a discussion of the relevant problems. In a recent research grant to the Technical University of Denmark and funded by the Danish Maritime Fund, the possible impacts of sulphur regulations on the Ro-Ro sector in Northern Europe, as well as possible mitigation actions and policy alternatives are being investigated. These will be reported in future publications.

5. Conclusions

This paper has attempted to discuss a limited sample of the issues that concern green maritime logistics. It has confirmed, among other things, that solutions for optimal environmental performance are not necessarily the same as those for optimal economic performance. As a private operator in the transport supply chain would most certainly choose optimal economic performance as a criterion, a challenge for transport policy-makers is to find the best way to influence the operator in his decision, so as to achieve results that are also good from a societal point of view, and move the solution closer to what is deemed more appropriate for the environment and for the benefit of society. This challenge may be easy to state but difficult to fulfil. It is hoped that the research of this author and his colleagues in recent years may contribute towards this goal.

Acknowledgments

Work on this paper was supported by an internal grant at the Technical University of Denmark.

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